Thermal Design of the ATROMOS Mars Lander

Elsie Hartman*, Hingloi Leung*, Freddy Ngo*, Syed Shah*, Nelson Fernandez*, Kenny Boronowsky*, Ramon Martinez*, Nick Pham*, Ed Iskander*, and Dr. Periklis Papadopoulos†
San Jose State University
Mechanical and Aerospace Department
One Washington Square
San Jose, California 95192

Marcus Murbach‡ and Erin Tegnerud‡
NASA/Ames Research Center
Moffett Field, California

The ATROMOS mission objective is to conduct life detection experimentation on the polar caps of Mars and to gather weather data for atmospheric characterization. The paper presented will detail the ATROMOS Mars Polar Lander thermal design and modeling. The thermal design study for the ATROMOS probe identified that the inside of the warm box that houses the critical instruments can maintain an operating temperature range, between –20 °C and 30 °C. The main heating sources in this design were three Radioactive Heating Units (RHUs) placed on a copper plate, and the boundary conditions were an outside temperature of –140 °C and an initial inside temperature of –40 °C. Using the Thermal Desktop software, several placements of the RHUs were considered, the warmest configuration being the RHUs huddled together in a triangular pattern in the center of the warm box, with an average temperature across the copper plate of 5.67 °C.

I. Introduction

There have been many missions to Mars over the years. Some have been successful and have furthered our understanding of our neighbor planet. On the other hand, some have not been successful, resulting in a loss of resources, such as time and money, and also a loss in the potential knowledge that could have been gained. Another new concept being applied to Mars missions is now coming to light: that of sending multiple, smaller spacecraft to the surface of Mars, so despite some failures, there will still be several other craft with a chance to succeed in its mission. These craft can be scattered across the surface and can collect data from all over the planet.

The ATROMOS mission is one made up of these smaller scout landers, bound for the Martian poles, a region, until recently, was relatively unexplored. One thing that makes ATROMOS challenging is to keep the electronics in it to a minimum and all the hardware as light and as power efficient as possible. This includes the thermal protection system. In earlier missions, spacecraft have been kept warm by using an active thermal system, which draws a lot of power and takes up a significant amount of weight. The key to the thermal protection system for Atromos is the Radioactive Heating Unit (RHU). An RHU is lightweight and some versions actually generate their own power.

Once at the Martian poles, ATROMOS will gather information on the possibility of life, and also on atmospheric conditions. Onboard will be a drill to collect soil samples, and an instrument mast to take temperature, pressure, and wind data, and also test for methane. The drill and instrument mast are placed outside the warmbox. Inside houses the other necessary instruments, such as the microcontroller, transceiver, accelerometer, batteries, and ultracapacitors. It is the instruments inside the warmbox that need to be heated to operating temperatures (-20 °C to 30 °C) in order to function properly.

* Aerospace student, San Jose State University, Mechanical and Aerospace Engineering Department
† Professor, San Jose State University, Mechanical and Aerospace Engineering Department
‡ Research engineer, NASA Ames Research Center, Moffett Field, CA

II. Setup

In order to get an idea of whether the Atromos could survive temperatures on Mars, a basic model was built in AutoCAD/Thermal Desktop.[1] This would simulate the worst-case scenario, assuming no additional insulation from the outer cylinder of Atromos and no additional heat input from the instruments. The model consists of three RHUs placed on top of a copper plate, which is placed inside a fiberglass warm box. Copper was chosen because it conducts heat well so the heat wouldn't be localized around the RHUs and would be distributed to the instruments spread throughout the box. Instruments are assumed to be thermally grounded to the copper plate. Fiberglass was chosen for the box because it is a good insulator and is also stronger than foam. Also, to minimize the contact between the copper and fiberglass box, four fiberglass pads were used to lift the plate up so less heat would leak out. Figure 1 shows the model below, and Table 1 lists the material properties used.

Dimensions:

Copper plate: 0.7 m long x 0.4 m wide x 1 mm thick

Warm box: 0.71 m long x 0.41 m wide x 0.1451 m tall x 1 cm thick

Fiberglass separators: 4.18 cm diameter x 2 mm thick

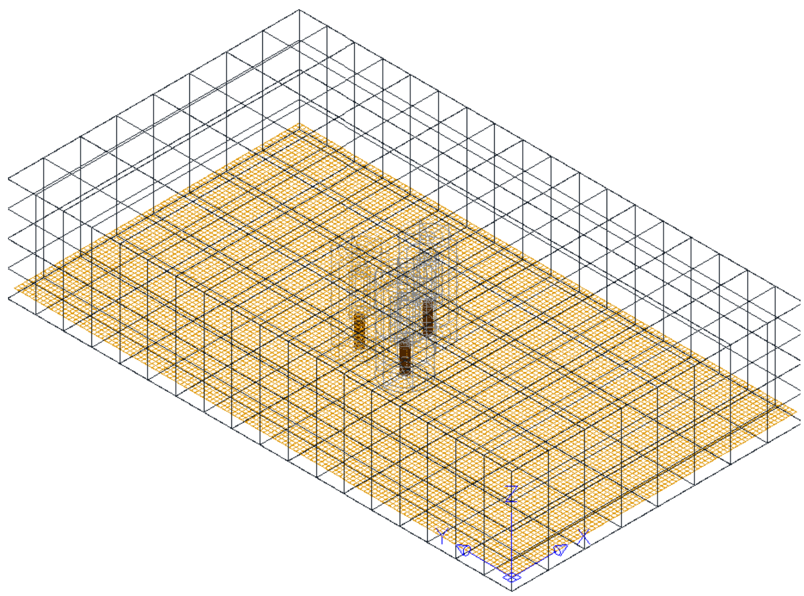

Figure 1. Layout of the RHUs on the copper plate inside the warm box.

Table 1. Material properties. [2]

Material	Conduction (W/m/°C)	Density (kg/m^3)	Specific heat (J/kg/°C)
Aluminum	205	2699	910
Ceramic	0.7	1600	840
Copper	237	2702	900
Fiberglass	1.1	2520	787
Stainless steel	15.6	8000	500

Even though the RHUs work using radioactive decay to heat the box, radiation was ignored in this model to keep it simpler for the time being. Inside the box and RHUs, conduction was used. To model the atmosphere, a convective fluid model was used.

The initial boundary conditions for the model are –140°C for the outside temperature and –40°C for the inside. The fluid model for the atmosphere was modeled using air at 6 Pa.

III. RHU Model

The RHUs are the primary heat source for the ATROMOS. They work by utilizing the radioactive decay of plutonium to heat it surroundings. The output is 1 W of heat transfer. To model this, a point source was used that conducted 1 W of heat to a surrounding aluminum canister. This canister was placed on a ceramic rod, and both were housed within an aluminum cylinder. The thermal properties of ordinary brick represent the ceramic. Three stainless steel wires were used to keep the inner canister secured and also to leak heat out directly to the aluminum. This heat leak helps to keep the inner canister from over heating. Below, Fig. 2 shows the inside arrangement of the RHU, and Fig. 3 shows the temperature map of a single RHU.

Dimensions:

Outer cylinder: 12 cm tall x 6 cm diameter x 2 mm thick; base is 2.5 mm thick

Ceramic: 4 cm tall x 1 cm diameter

Inner canister: 5 cm tall x 3 cm diameter x 2 mm thick

Steel wires: 4.72 cm long x 1.57 mm diameter

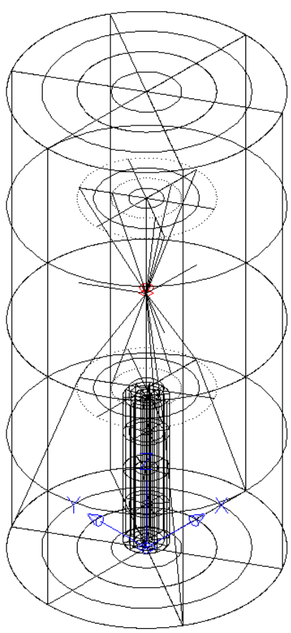

Figure 2. Thermal Desktop model of an RHU. *The point source can be seen in the inner canister with conduction contacts.*

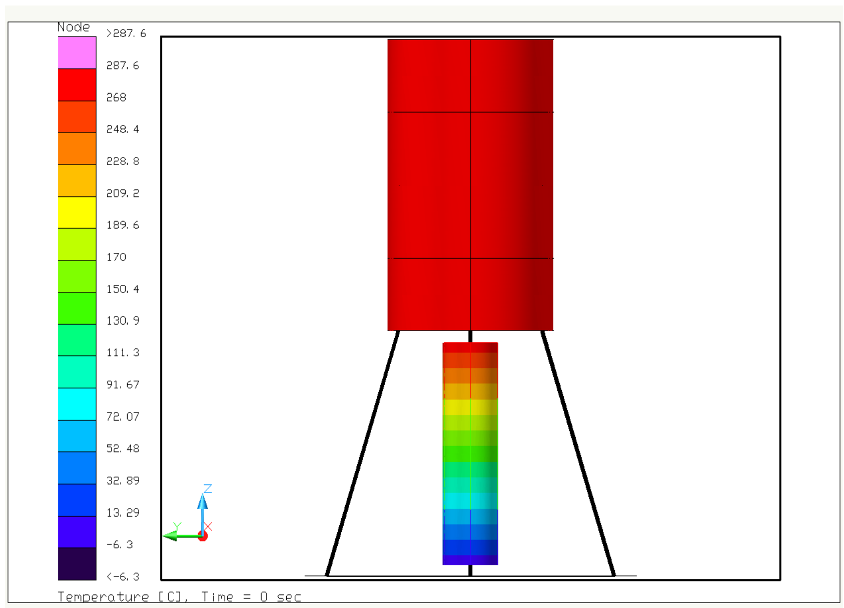

Figure 3. Temperature plot of the RHU. *Temperature difference across ceramic is 282 ºC.*

IV. RHU Test Configurations

With the RHUs modeled and the initial boundary conditions set, the warmest configuration of three RHUs needed to be found. Nine different cases were run. Types of configurations tested were RHUs placed:

1) linearly and equidistant
2) at the centroids of three equal areas
3) in equilateral triangles

V. Results

In general, the warmer configurations were when the RHUs were huddled close together and near the center of the plate. The colder configurations were with the RHUs spread further out, especially linearly.

The warmest solution was huddled RHUs forming a triangle placed at the center of the plate, with the base of the triangle going along the length of the plate. The average temperature across the plate was 5.672 °C.

The coldest solution was the RHUs placed linearly along the length of the plate, covering equal areas. The steady state temperature was 4.417 °C. This means that the difference between the warmest and coldest placements tested is only 1.255 °C. All results are listed in Table 2 with the corresponding Figs. 4-12 below.

Table 2. Summary of results from warmest to coldest, with pictures below.

Placement	Temperature (ºC)	Placement	Temperature (ºC)
Huddled 2	5.6718	**Equilateral 3; d=10 cm**	5.4735
Huddled 1	5.6644	**Centroid 2**	5.2722
Equilateral 3; d=5 cm	5.5569	**Equidistant**	5.2667
Equilateral 1	5.5565	**Centroid 1**	4.5379
Equilateral 2	5.5419	**Equal area**	4.4173
Equilateral 3; d=8 cm	5.5172		

The diameter of the fiberglass thermal separators between the warm box and plate had an extreme impact on the final temperature of the model. The final diameter of 4.18 mm was chosen because it gave an average temperature close to 5 °C using the equidistant placement of RHUs. If more heat had to be leaked out, the diameter of the separators was increased. If the temperature was too cold, the diameter was decreased so less heat would be lost. All of the following figures, Figs. 4-12, correspond to the final diameter selected.

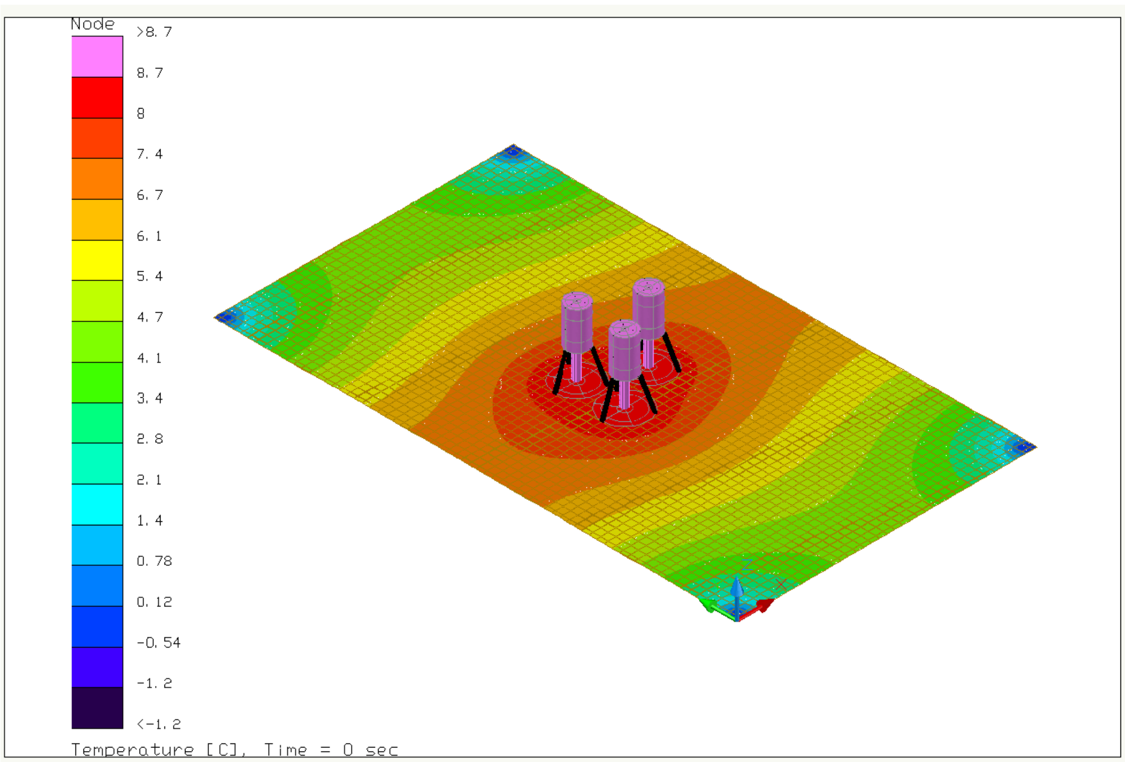

Figure 4. Huddled 2. *Configuration with triangular base along length of plate.* T_{ave} *= 5.67 ºC.*

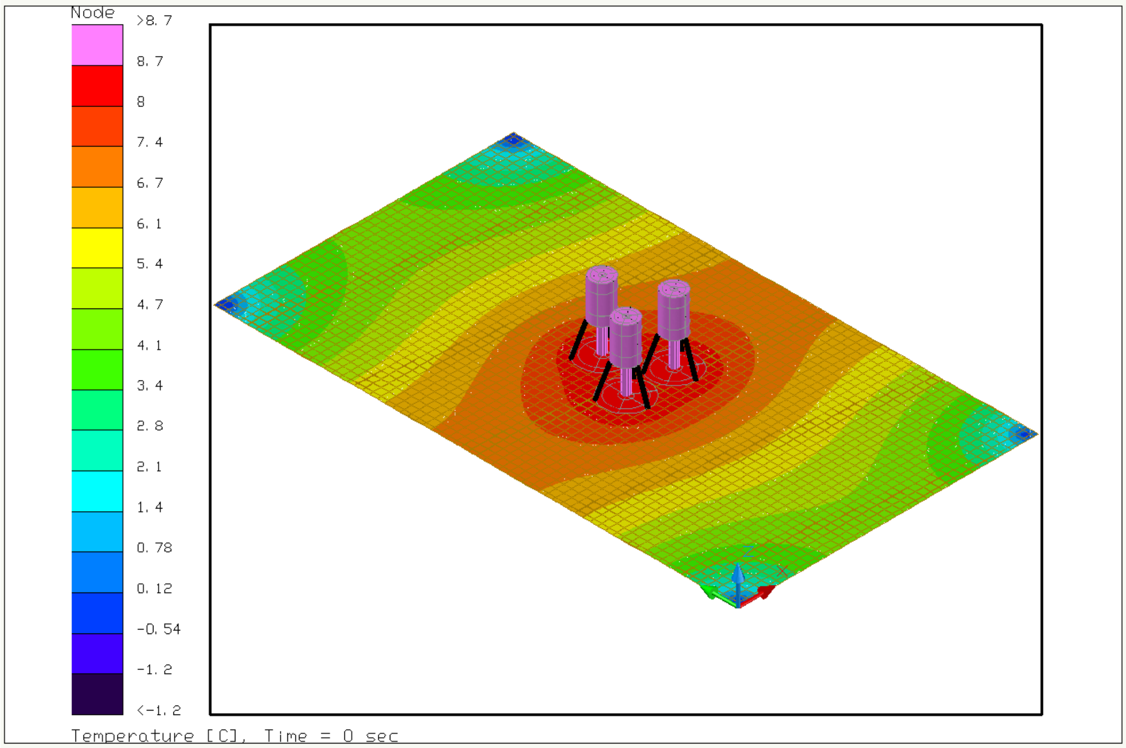

Figure 5. Huddled 1. *Configuration with triangular base along width of plate.* T_{ave} *= 5.66 ºC.*

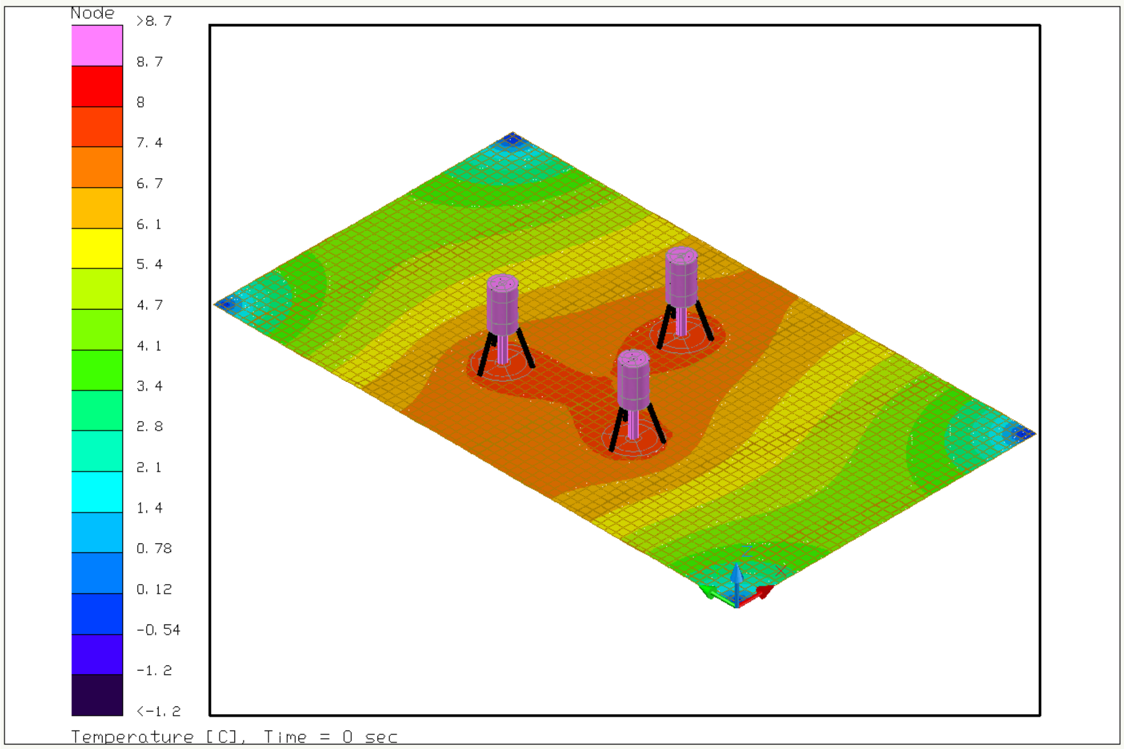

Figure 6. Equilateral 1. *Centered, with* T_{ave}*= 5.56 ºC.*

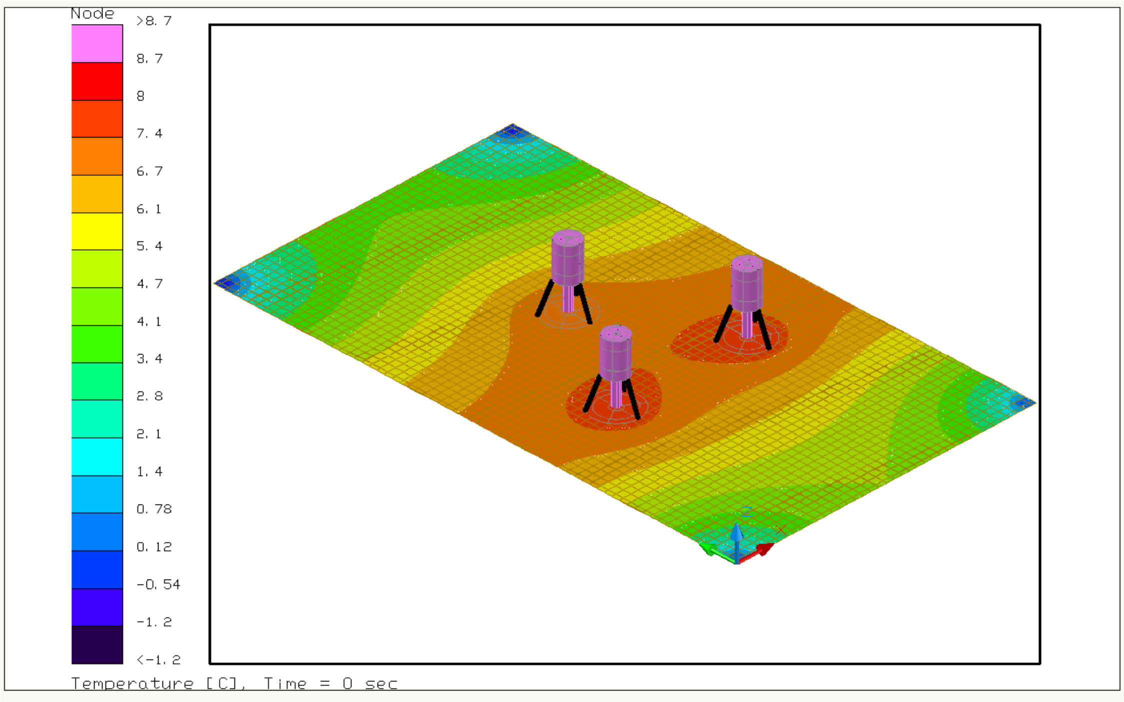

Figure 7. Equilateral 2. *Centered with* T_{ave}*= 5.54 ºC.*

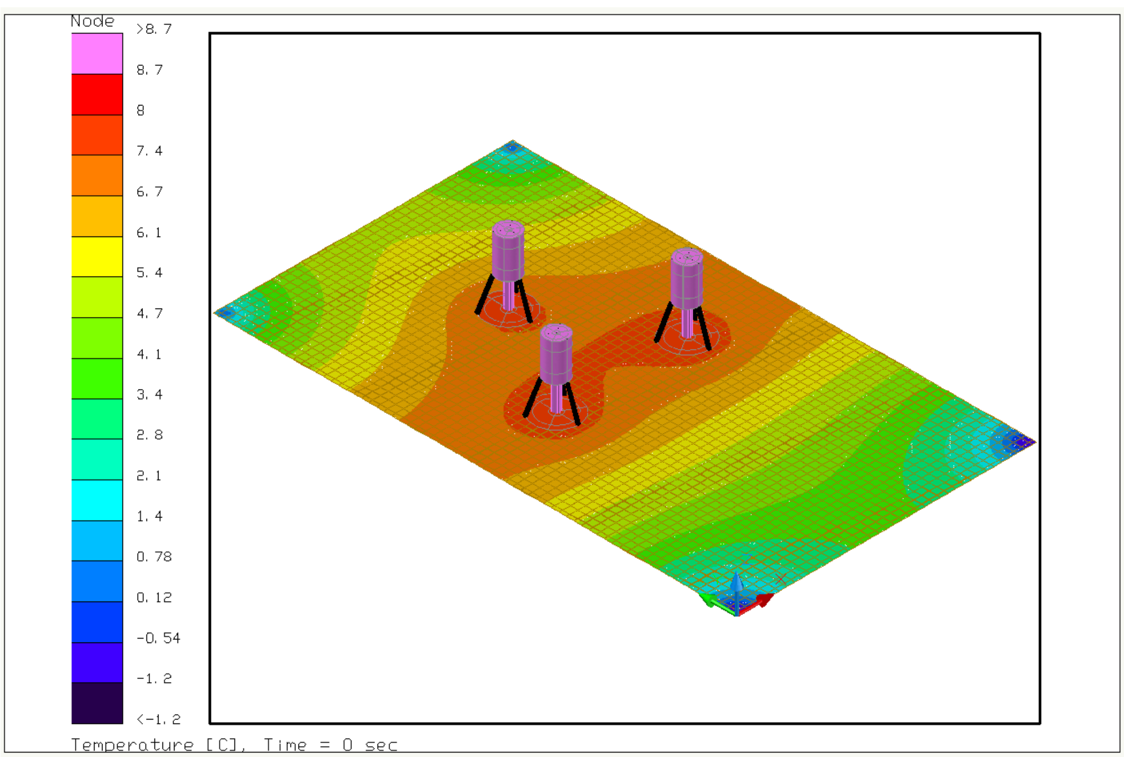

Figure 8. Equilateral 3. *Configuration displaced along y-direction 0.008m.* T_{ave} *= 5.52 ºC.*

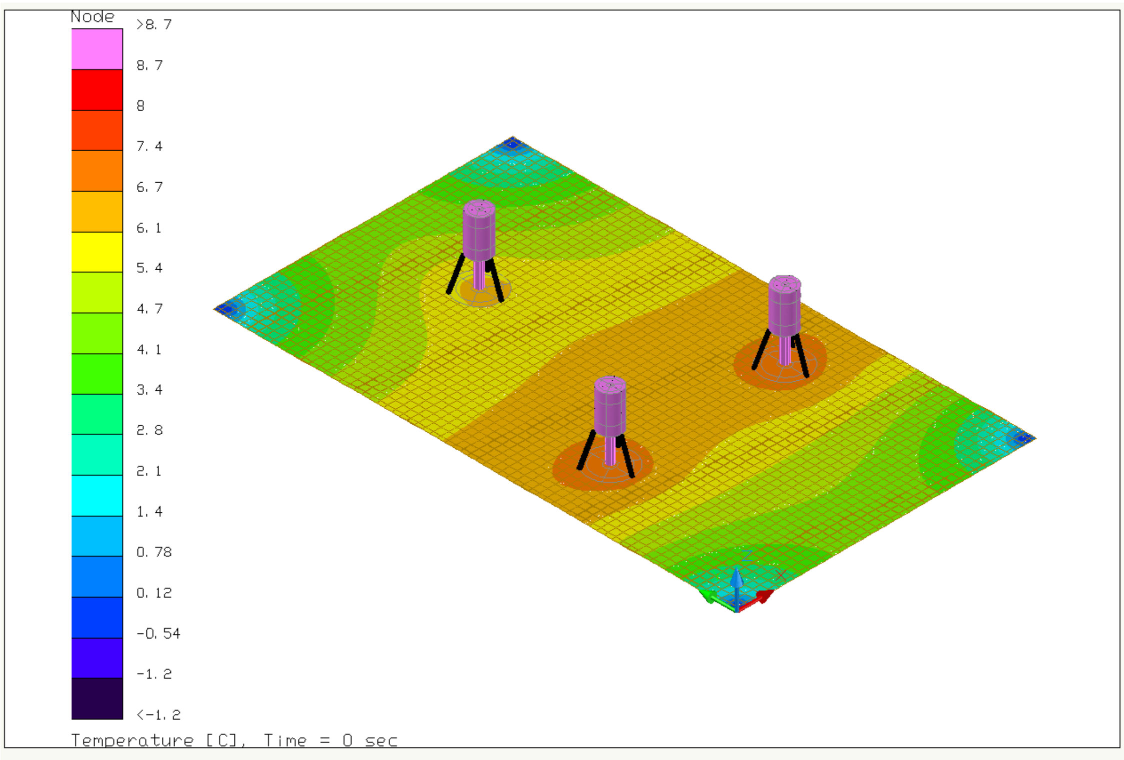

Figure 9. Centroid 2. *RHUs placed at the centroids of three equal areas. T_{ave}=5.27 ºC.*

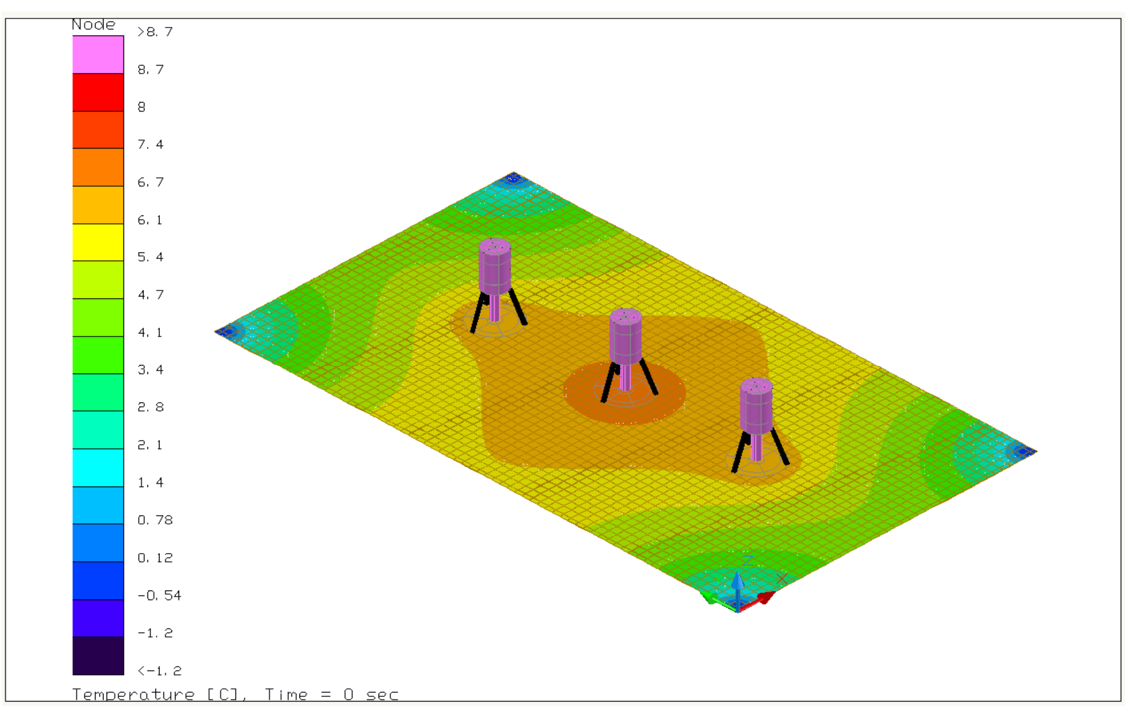

Figure 10. Equidistant. *Linear placement, equally spaced between RHUs and ends of plate. T_{ave}=5.27 ºC.*

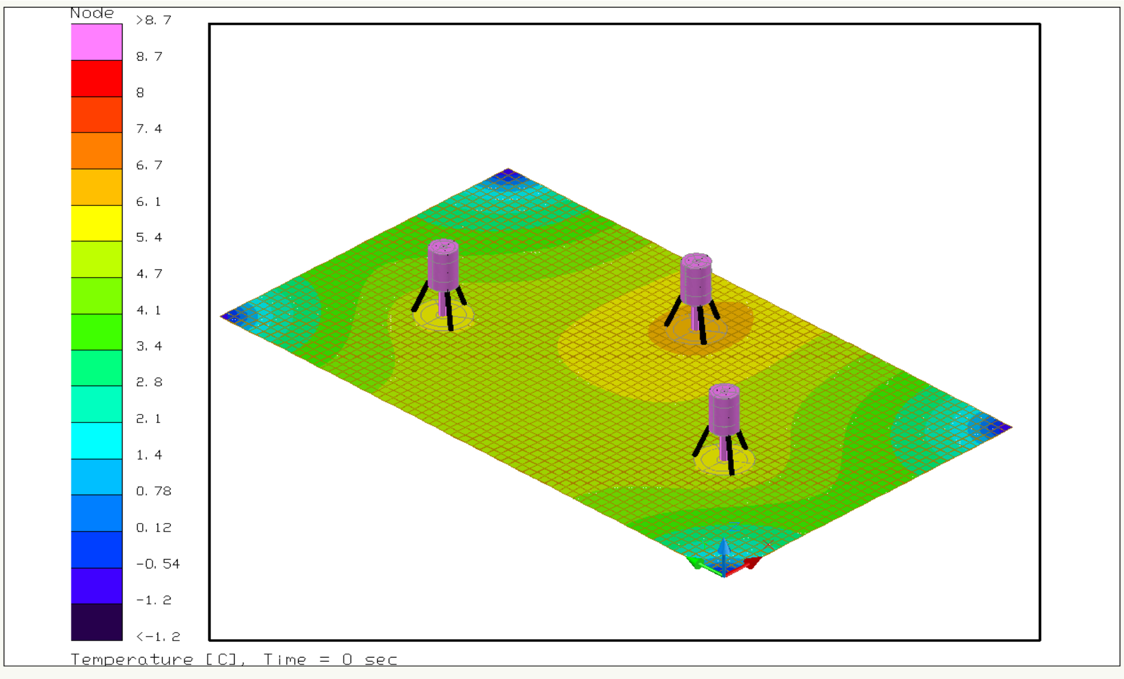

Figure 11. Centroid 1. *Another placement of RHUs at centroids.* T_{ave}*=4.54 ºC.*

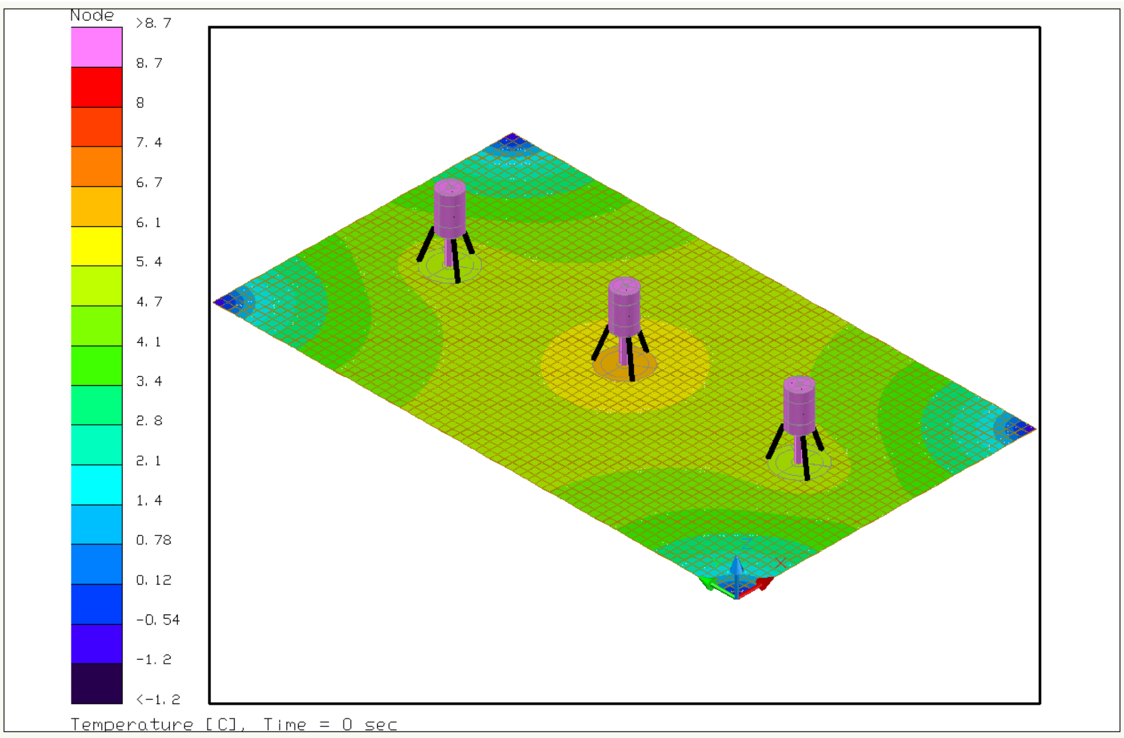

Figure 12. Equal areas. *Linear placement with RHUs covering equal areas.* T_{ave}*=4.42 ºC.*

VI. Discussion

After the configurations were run, it became apparent that the closer the RHUs are to each other, the warmer the average temperature is across the plate. However, the difference between the warmest and coldest placements was only 1.3 °C. With this in mind, if the instruments interfered with a close proximity placement of the RHUs, the steady-state result in temperature wouldn't be much different than if the RHUs had to be spread further out. According to these models, it would still result with an inner temperature between –20 °C and 30 °C. A major factor in the final steady-state temperature was the fiberglass separators. The temperature could be adjusted easily by changing the diameter of their cross-sections. The diameter listed in the above dimensions is a result of fine-tuning the temperature to be centered within the operating temperature range.

VII. Conclusion

There are several improvements that can be made to this model, since the progress so far is only an initial step. One improvement is to include radiation calculations. Another is inputting the instruments to see how much they will contribute to heating the inside of ATROMOS. Also, insulation and other materials could be looked at to see if perhaps less RHUs could be used. One important change would be to model the plate not as solid copper, but instead as something similar to a circuit board; this would help to route heat more efficiently to the instruments.

Acknowledgments

Many thanks to Marcus Murbach and Erin Tegnerud, our advisors out of NASA Ames Research Center, who provided a wealth of information on RHUs, Mars, and spacecraft in general. Also, thanks to Dr. Periklis Papadopoulos, our project and academic advisor, who strived to keep us on track, keep our project as close to the real thing as we could get, and who always had our best interests at heart.

References

[1]Thermal Desktop, Software Package, Version 5.0, C&R Technologies, Littleton, CO

[2]MatWeb – Material Property Data. < http://www.matweb.com>